Shortcuts for marine conservation planning: The effectiveness of socioeconomic data surrogates

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A R T I C L E   I N F O

Article info

Article history:
Received 3 November 2009
Received in revised form 15 February 2010
Accepted 20 February 2010
Available online 20 March 2010

Abstract

Marine protected area (MPA) networks designed without consideration of the interests of local communities are likely to fail. However, in many regions where conservation action is needed most urgently, socioeconomic data are not available at spatial scales relevant to conservation planning. In the Philippines, the primary stakeholders relevant to conservation efforts in coastal waters are small-scale fishers. Unlike commercial fisheries, no logbook data are kept to record fishers’ spatial effort and usage patterns. We investigated the effects of including different surrogates for small-scale fishing effort in the systematic design of an MPA network for Siquijor Province. We compared a reserve selection scenario in which socioeconomic data were not considered with four different surrogates for fishing effort and with empirical data on the spatial distribution of fishing effort collected through interviews. We assumed that minimising opportunity costs to fishers would increase the likelihood that they would support and comply with MPA implementation, resulting in more effective conservation. Surrogates modelled on the number of fishers or boats in each community consistently outperformed those based on population census data. However, none of the surrogates we tested were able to accurately predict fine-scale resource use patterns. Whilst socioeconomic surrogates may be able to assist conservation planners to identify region-scale opportunities where conservation objectives may be met more easily, they cannot act as a shortcut for comprehensive consultation with communities, which will be required to identify actual sites for MPA implementation.

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1. Introduction

A unifying theme emerging from recent empirical studies of marine conservation initiatives is that socioeconomic, cultural and political factors are critically important to their success (Lundquist et al., 2005). For conservation plans to be implemented successfully, they must have support from stakeholders and local communities. This is especially true in regions where resources are insufficient for active enforcement of management initiatives, and compliance must therefore be voluntary (Walmsley and White, 2003; Cinner et al., 2005; Alcala and Russ, 2006; McClanahan et al., 2006).

One such region is the Coral Triangle (comprising Indonesia, Malaysia, the Philippines, Solomon Islands, Papua New Guinea and Timor Leste, Fig. 1). Widely acknowledged as a global priority for marine conservation (Roberts et al., 2002; Carpenter and Springer, 2005), the region is home to 33% of the world’s coral reefs, which, in addition to their biodiversity value, provide food security and livelihoods for millions of people (Coral Triangle Initiative, 2008). No-take marine protected areas (MPAs) have become a key management tool to mitigate threats to marine resources in this region, both from the impacts of global climate change and local threats from overfishing, unsustainable fishing practices and habitat degradation (Govan et al., 2009; Weeks et al., 2010). However, failure to adequately incorporate socioeconomic factors has resulted in poor management effectiveness of many MPAs (Christie and White, 1997), and plans that fail to be translated into conservation action (Knight et al., 2008; Polasky, 2008). As planners attempt to scale up existing MPAs into ecologically representative, connected and resilient MPA networks (Coral Triangle Initiative, 2008; Lowry et al., 2009), they will need to carefully balance the potential biodiversity conservation benefits and socioeconomic viability of their designs (Klein et al., 2008).

Systematic conservation planning is the process of locating, configuring, implementing and maintaining areas that are managed to promote the persistence of biodiversity (Margules and Pressey, 2000). This approach is often supported by software designed to assist planners to identify protected area networks that achieve quantitative targets for biodiversity representation for a minimal cost. In this context, ‘cost’ may refer to the financial cost...
of acquiring, designating and managing protected areas or foregone opportunity costs to resource users (see Naidoo et al., 2006). Considering spatial variation in costs enables planners to use limited funds available for conservation to best effect, and to reduce social conflict by minimising the overlap between protected areas and resource use (Ban and Klein, 2009).

Despite widespread agreement that they ultimately determine the success of conservation efforts (Sale et al., 2005), much research to date has neglected the social and economic aspects of planning (Naidoo and Adamowicz, 2006). Early attempts at conservation planning considered socioeconomic factors as a post hoc filter for areas identified using biological data alone (Stewart and Possingham, 2005). Emphasis on the ‘efficiency’ of conservation plans (Pressey et al., 1993) typically focussed on minimising the financial acquisition cost of terrestrial protected area networks (Ando et al., 1998), or the area and boundary length of MPA networks (Leslie et al., 2003), as a crude surrogate for management costs. Only relatively recently have conservation planners turned their attention to the problem of socioeconomic viability, by considering opportunity costs to resource users to explicitly account for the social costs of establishing protected areas (e.g. Cameron et al., 2008; Klein et al., 2008).

Efforts to explicitly incorporate socioeconomic factors in the design of MPA networks are likely to be constrained by a lack of quantitative data (Naidoo and Adamowicz, 2006; Carwardine et al., 2008). Conservation planning undertaken at regional scales allows for the consideration of complementarity (Vane-Wright et al., 1991) and connectivity (Almany et al., 2009) between protected areas. However, this approach also demands that biological and socioeconomic data are consistent in extent and resolution across the planning region, to avoid data-driven bias in site prioritisation (Grand et al., 2007).

Although many socioeconomic factors require consideration during the implementation of marine conservation initiatives, MPA location is primarily influenced by opportunity costs to resource users (Ban and Klein, 2009). Several studies have demonstrated that incorporating data on the distribution of commercial and recreational fishing effort can substantially reduce economic losses incurred by the fishing industry as a result of MPA implementation (Stewart and Possingham, 2005; Richardson et al., 2006; Klein et al., 2008). However, in the Coral Triangle, small-scale fishers are the primary stakeholders in conservation planning for coastal waters. The poor availability of data for small-scale fisheries in particular, compared to logbooks and records typically kept for commercial fisheries, is likely to frustrate conservation planners in the region (Ban et al., 2009).

Coastal resource use in the Coral Triangle is extremely complex; a large number of fishers from different communities employ different gear types to target different species. In this context, collecting empirical data on the spatial distribution of resource use at scales relevant to conservation planning is logistically challenging (Green et al., 2009). For this reason, ‘shortcuts’ that take advantage of existing data sources, such as population census data, are of interest. Just as biodiversity surrogates are employed to compensate for gaps in biological data (Rodrigues and Brooks, 2007), socioeconomic surrogates can be used to represent the cost of conservation in the absence of empirical data (Ban and Klein, 2009). Previous studies have used surrogates based on population...
pressure (Ban et al., 2009) or the density of small boats (Sala et al., 2002) as a proxy for fishing pressure.

How well socioeconomic surrogates reflect the true cost of conservation action to stakeholders and communities is an important and unresolved question (Adams et al., 2009; Ban and Klein, 2009). If simple functions of population or fishing boat registration data can predict the spatial distribution of fishing effort accurately, these data can (and should) be used to inform regional-scale conservation planning. However, if they represent real resource use patterns poorly, using such data may result in less effective conservation plans that do not earn community support. In this case, using coarse-resolution surrogates may be no better than assuming costs are homogenous, or proportional to the area protected (Richardson et al. 2006).

Much effort has been directed at assessing the adequacy of biodiversity surrogates in marine conservation planning (e.g. Ward et al., 1999; Gladstone and Alexander, 2005; Beger, 2007; Mumbey et al., 2008). In contrast, where socioeconomic surrogates have been employed, they are typically assumed to be an accurate representation of true conservation costs. Although a few studies have compared different cost surrogates (e.g. Carwardine et al., 2008; Ban et al., 2009), we are not aware of any that have tested their accuracy empirically.

We investigated the ability of socioeconomic surrogates to predict the opportunity cost to small-scale fishers of establishing an MPA network for Siquijor Province, Philippines. We compared MPA networks that were designed without consideration of socioeconomic data with those that incorporated four different surrogates for fishing effort and empirical data on the spatial distribution of fishing effort collected through interviews. Our aim was to assess the effectiveness of each surrogate at predicting empirical cost, and their ability to reduce the impact of an MPA network on fishers.

2. Methodology

2.1. Study area

Our study area was Siquijor island, Philippines (Fig. 1). More than two thirds of the population (c. 88,000) live in coastal barangays (the smallest political unit in the Philippines, analogous to a village or city ward), and small-scale fisheries contribute significantly to income and food security. Following the Philippine Local Government Code of 1991 (Republic Act 7160) and Philippine Fisheries Code of 1998 (Republic Act 8550), commercial fishers are excluded from operating within 15 km of the coastline. These coastal waters are reserved for small-scale fishers, who use small, typically non-motorised, outrigger boats and employ a large variety of fishing gears to target a diverse range of species. At present, Siquijor has 15 designated no-take MPAs, all smaller than 0.5 km² (Weeks et al., 2010).

2.2. Fishing effort data

Data on the number of fishers and boats, and the spatial distribution of fishing effort in each barangay was collected through semi-structured interviews (n = 57) with members of coastal communities. Time constraints limited our survey to one interview per barangay, and interviewees were asked to summarize patterns of fishing effort for all fishers in their community. Where possible, interviewees targeted those likely to have extensive knowledge of fishing practices throughout their barangay: members of a Fishermen’s Association committee or barangay councillors. Interviews were conducted between April and July 2009 by A. B., an ex-resident of Siquijor.

Interviewees were shown enlarged maps of Siquijor, with the location of barangays, prominent coastal features and marine habitats (coral reefs, seagrass, mangroves) marked. The maps were laminated to allow fishers to draw and write information directly onto the map. Where interviewees were not comfortable with this approach, they were prompted to describe the limits of fishing grounds verbally, and this information was transferred onto the map by the interviewer. Interviewees were first asked to estimate the total number of fishers in their barangay, the number of motorised and non-motorised boats. They were then asked to identify the locations of fishing grounds used by members of their community on the map, and to estimate the number of fishers from their barangay using each site.

2.3. MPA network selection

We used the conservation planning software Marxan (Ball and Possingham, 2000; Possingham, 2000) to identify MPA networks that fulfilled a conservation objective whilst minimising foregone opportunity costs to small-scale fishers. Marxan uses a simulated annealing algorithm with iterative improvement to generate multiple MPA network solutions that satisfy specified conservation objectives for a low cost. These solutions typically have different spatial configurations, providing planners with flexibility. In addition to identifying the ‘best’ MPA network for each scenario (that which meets targets for the lowest cost), Marxan reports selection frequency scores for each planning unit: the number of times each planning unit was selected in (in this instance) 1000 runs of the algorithm. Selection frequency scores provide a useful indication of the conservation importance of each planning unit (Stewart et al., 2007).

MPAs in the Philippines are typically established to conserve coral reef-associated habitats and ensure the sustainability of the fisheries dependent upon them. To date, no MPAs have been established to target open water habitats (Weeks et al., 2010). We thus defined our planning region by the extent of targeted conservation features (see below, and Fig. 1).

We divided the planning region into regular hexagonal planning units of 0.05 km². This planning unit size was selected to be at a scale relevant to management: the median size of no-take MPAs in the Philippines is 0.12 km², and the minimum for Siquijor, 0.04 km² (Weeks et al., 2010). Thus, a single planning unit, or two contiguous units would be a typical size range for a no-take MPA in the region. Socioeconomic constraints, including the low spatial mobility of fishers, make the implementation of larger MPAs less feasible. Consequently, in contrast to conservation planning studies located in developed countries (e.g. Fernandes et al., 2005; Klein et al., 2008), a scattered system of small MPAs is more practical than fewer, larger ones. For this reason, we did not use Marxan’s ‘boundary-length modifier’ (Possingham, 2000) to express a preference for spatially compact MPA networks.

Following the Philippine Marine Sanctuary Strategy (Areco et al., 2004), which has been adopted by the Coral Triangle Initiative (Coral Triangle Initiative, 2008), our conservation objective required representation of 10% of the area of coral reef-associated habitat types identified from satellite imagery: fringing reefs, sunken shoals, seagrass, lagoons and mangroves. We identified six distinct reef fish ‘bioregions’ using multivariate statistics on underwater visual census data collected at 26 survey sites around the island (Fig. 1) (Weeks & Stockwell, unpublished data). We required 10% of each habitat type to be represented in each bioregion, resulting in 19 targeted conservation features (not all habitat types were present in all bioregions). We used ArcGIS to calculate the area of each conservation feature within each planning unit. Cost values were then assigned to planning units as described below (Section 2.4).
2.4. Data scenarios

We implemented Marxan for six different reserve selection scenarios, each with different socioeconomic costs (Table 1). We compared a scenario in which socioeconomic data were not considered (scenario a) with four different surrogates of small-scale fishing effort (scenarios b–e) and empirical data for the spatial distribution of fishing effort (scenario f; Table 1). We selected socioeconomic surrogates that could be derived from population census data (scenario b and c), as these data are typically available even in otherwise data-poor regions. We also tested surrogates based on the number of fishers or boats (scenario d and e): these data may be pre-existing, and are otherwise relatively cheap and quick to collect (compared to mapping the spatial distribution of fishing effort). Fishing effort surrogates were intended to represent the foregone opportunity cost to small-scale fishers if that site were to be designated as a no-take MPA. We assumed that minimising opportunity costs to fishers would increase the likelihood that they would support and comply with MPA implementation, resulting in more effective conservation. As our planning region was limited to inshore coastal waters, we did not consider the interests of commercial fishers as stakeholders.

For scenario a, costs were considered to be spatially homogenous, with the cost of each planning unit (each site available for inclusion in the MPA network) equal to its area. Under this scenario, sites were selected based on their biodiversity value alone, with no explicit consideration of socioeconomic values, and the site-selection objective was to minimise the total area of the MPA network. For all other scenarios, the objective was to reduce the cost of the MPA network. For scenarios b and c, costs were modelled from population census data (http://www.census.gov.ph/; accessed May 2009), as a function of barangay population (scenario b) or coastal population density (scenario c). Coastal population density was derived by dividing barangay population by the length of the barangay coastline, calculated in ArcGIS (version 9.2; ESRI, Redlands, California). Cost values were assigned to planning units using a linear distance decay, such that units closer to the coastline had a higher cost than those further offshore (out to 10 km) and units adjacent to barangays with larger populations had greater cost than those adjacent to smaller populations. For scenario d, costs were modelled from the estimated number of fishers (from interview data) in each barangay (scenario d), following the same approach. In scenario e, costs were modelled as a function of the estimated number of fishing vessels (from interview data) of different types and the distance typically travelled using that vessel type. Based on responses given during interviews, fishers using motorised boats were assumed to have spatial mobility of 10 km, those using non-motorised boats 3 km, and beach-based gears (beach-seine, gleaners and spearfishers) 1 km.

Finally, scenario f used empirical cost values: the number of fishers using each site, from interview data. Spatial information collected during interviews was digitized in ArcGIS. Each fishing ground polygon was assigned a score of the estimated number of people fishing there; scores were summed for overlapping polygons, and then rescaled to match the other cost layers (all costs were relative, on a scale of 0–1000). The spatial precision of fishing ground polygons identified during interviews was variable: whilst some interviewees identified precise locations of favoured sites, others gave a broader summary of the areas fished by members of their community. This variability resulted in sharp gradients in cost values at the edges of fishing ground polygons, which we felt did not accurately represent real spatial resource use and would have excessively influenced our results. To reduce this effect, we smoothed the cost values for the empirical data scenario using the Neighbourhood Statistics tool in the Spatial Analyst extension for ArcGIS. In all cases, cost values represent a relative measure of the importance of each site to small-scale fishers, rather than an estimate of economic value.

Our surrogate models would be unable to predict the absence of fishing effort within existing no-take MPAs or increased effort along their boundaries (Alcala and Russ, 2006). Thus, including areas of zero fishing effort inside existing MPAs in our empirical data would have resulted in large differences between predicted and empirical values at those sites. To avoid this bias, which may have excessively driven our results, we did not include existing MPAs in our empirical maps of fishing effort and redistributed effort in adjacent fished areas across the MPAs.

2.5. Analyses

2.5.1. Effectiveness of surrogates at predicting empirical cost

We assessed the ability of surrogates to predict the spatial distribution of fishing effort by comparing the cost values assigned to planning units under each data scenario with pairwise Spearman’s rank correlation (r). All statistical analyses were undertaken with the statistical software package ‘R’ (R Development Core Team, 2008).

2.5.2. Comparing MPA networks

For each scenario, we categorized the conservation importance of planning units based on their Marxan selection frequency: units selected no more than would be expected by chance (1 standard deviation to the right of the mean) were considered of low importance; those selected slightly more than by chance (2 standard deviations to the right of the mean) of medium importance; and those selected much more frequently than chance (the rest of the tail) were considered highly important.

We used two methods to compare the spatial similarity of Marxan outputs for the different scenarios (i.e. how similar the planning units selected for one network are to the planning units in another network). First, we examined the overlap of conservation importance categories for each scenario using Cohen’s Kappa statistic (κ); a chance-corrected measure of spatial agreement. Kappa values range from +1, indicating complete agreement (or perfect overlap between categories), to −1, indicating complete disagreement. A Kappa statistic of 0 indicates overlap due to chance.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost value assigned to each planning unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>a (area)</td>
<td>Area*</td>
</tr>
<tr>
<td>b (population)</td>
<td>Linear distance function of barangay population, with influence distance of 10 km</td>
</tr>
<tr>
<td>c (coastal density)</td>
<td>Linear distance function of coastal population density, with influence distance of 10 km</td>
</tr>
<tr>
<td>d (fishers)</td>
<td>Linear distance function of estimated number of fishers per barangay, with influence distance of 10 km</td>
</tr>
<tr>
<td>e (boats)</td>
<td>Function of estimated number of fishing vessels of different types, and the spatial mobility of that vessel type (motorised boats = 10 km, non-motorised boats = 3 km, beach-based gears = 1 km)</td>
</tr>
<tr>
<td>f (empirical)</td>
<td>The estimated number of fishers using each site, derived from interviews</td>
</tr>
</tbody>
</table>

* (Planning units were typically 0.05 km² except at the land-sea interface where units were clipped to the coastline, resulting in smaller units).
ond, we compared the selection frequency of planning units under different surrogate data scenarios using hierarchical cluster analysis (Euclidean distance, Ward’s clustering method).

2.5.3. Effectiveness of surrogates at reducing the cost of MPA networks

To assess the ability of different socioeconomic surrogates to reduce the impact of an MPA network on fishers, we calculated the mean cost of MPA networks identified by Marxan as the sum of the empirical cost of selected planning units. We tested the significance of cost differences with one-way analysis of variance (ANOVA) and post hoc Tukey’s honest significant differences (HSD) tests.

2.5.4. Existing MPAs

Two assumptions are central to our analysis: first, that the spatial distribution of fishing effort accurately represents opportunity costs to small-scale fishers; and second, that minimising opportunity costs to fishers increases the likelihood of successful MPA implementation. We tested these assumptions using the hypothesis that existing MPAs would have a lower cost than other sites under the empirical data scenario. Existing MPAs have been established following an opportunistic approach, with locations determined largely by the likelihood of successful implementation; we therefore expect that these sites would have lower fishing pressure (causing less conflict) than other areas.

3. Results

3.1. Effectiveness of surrogates at predicting empirical cost

Surrogates varied in their ability to predict empirical cost patterns (Fig. 2). Population (scenario b) and coastal population density (scenario c) were poor predictors of the spatial distribution of fishing effort ($\rho = 0.19$ and $\rho = -0.14$ respectively, $p < 0.001$ for both). These scenarios predicted greatest cost values along the north-west coast of Siquijor, whereas empirical data showed that fishing pressure was in fact highest along the south-west coast (Fig. 2). Surrogates based on the number of fishers (scenario d) and boats (scenario e) were positively correlated with empirical cost, although not strongly so ($\rho = 0.62$ and $\rho = 0.55$ respectively, $p < 0.001$ for both).

3.2. Spatial similarity of MPA networks identified using different surrogates

All data scenarios produced MPA network solutions that achieved the conservation objective (Table S1). Kappa statistics indicated that scenarios e (boats) and d (fishers) were most similar to empirical data in terms of the conservation importance of planning units ($\kappa = 0.377$ and $\kappa = 0.312$ respectively, $p < 0.001$ for both; Table 2, Fig. 3). MPA networks designed without socioeconomic data (scenario a) showed no spatial agreement in selection frequency categories with those based on empirical data ($\kappa = -0.058$, $p < 0.05$).

Hierarchical cluster analysis of Marxan results for each scenario (Fig. 4) indicates that the spatial pattern of selected sites varied greatly between scenarios; clustered solutions have similar spatial configurations of selected sites. With the exception of scenarios b (population) and c (coastal density), which cannot be distinguished, each of the socioeconomic data scenarios forms a distinct cluster. The empirical data scenario cluster appears as an outlier, indicating low levels of similarity with MPA networks identified using any of the surrogates (Fig. 4).

Fig. 2. The foregone opportunity cost to small-scale fishers of MPA implementation under different socioeconomic data scenarios used in our analyses: area (a), population (b), coastal population density (c), fishers (d), boats (e) and empirical data (f). In all cases, cost values are relative, and not intended to represent the economic value of a site.
Table 2
Cohen’s Kappa statistics ($\kappa$) for spatial agreement between selection frequency categories under each cost scenario.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>a (area)</th>
<th>b (population)</th>
<th>c (coastal density)</th>
<th>d (fishers)</th>
<th>e (boats)</th>
</tr>
</thead>
<tbody>
<tr>
<td>b (population)</td>
<td></td>
<td>-0.070**</td>
<td>0.063***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c (coastal density)</td>
<td></td>
<td>0.752***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d (fishers)</td>
<td>-0.072**</td>
<td>0.540***</td>
<td>0.397***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>e (boats)</td>
<td></td>
<td>0.425***</td>
<td>0.357***</td>
<td>0.461***</td>
<td></td>
</tr>
<tr>
<td>f (empirical)</td>
<td>-0.058*</td>
<td>0.216***</td>
<td>0.157***</td>
<td>0.312***</td>
<td>0.377***</td>
</tr>
</tbody>
</table>

* A Kappa statistic of 1 indicates complete agreement, 0 indicates overlap due to chance.

Fig. 3. Marxan results for two parts of the study region: ‘best’ networks and selection frequency of planning units under different socioeconomic data scenarios: area (a), population (b), coastal population density (c), fishers (d), boats (e) and empirical data (f).
through local community support for management actions (Alcala and Russ, 2006; Green et al., 2009). One of the many challenges that face planners attempting to scale up existing, largely community-based, conservation efforts into effective regional MPA networks is the lack of informative socioeconomic data at the appropriate scale (Ban et al., 2009; Green et al., 2009). We assessed the ability of different opportunity cost surrogates to reduce the negative impacts of MPA network implementation on small-scale fishers, the primary stakeholders in coastal waters of the Coral Triangle.

Opportunity costs to resource users are the principal costs involved in conserving marine ecosystems, where acquisition and transaction costs (Naidoo et al., 2006) are atypical, due to the common-pool nature of marine resources (Ostrom et al., 1999). We did not consider spatial variation in management costs. Management costs associated with MPA establishment and infrastructure (e.g. marker buoys) are unlikely to exhibit spatial variation at this scale. Although it has been assumed that enforcement costs are reduced when MPAs are within sight of a community (McClanahan et al., 2006; Ban et al., 2009), existing MPAs in Siquijor show exceptions to this rule: at least two MPAs are located away from their barangays, with enforcement achieved through 24-h surveillance by volunteers stationed in a guard house.

Our study is the first to empirically test the adequacy of surrogates for small-scale fishing effort in conservation planning. However, our empirical data are not without their limitations. Fishers’ spatial preferences were typically not described at a sufficiently fine scale to guide the placement of individual MPAs. In many cases, interviewees identified all of the reef area adjacent to their barangay as a fishing ground. In order to place a no-take MPA within that area, more comprehensive consultation with communities would certainly be required.

In agreement with other studies, we found that using spatially homogenous costs (i.e. area) resulted in MPA networks that had a greater impact on resource users than when more specific cost measures were used (Stewart and Possingham 2005; Klein et al. 2008). Socioeconomic surrogates differed in their ability to predict spatial patterns of fishing effort and to reduce the costs of MPA network implementation to stakeholders. Surrogates based on the number of fishers or boats in each barangay outperformed those based solely on population census data. Our findings support those of Carwardine et al. (2008) who warn that using inappropriate cost measures can lead to costly conservation mistakes. In this context, using population density as a surrogate would direct conservation planners towards locating MPAs in areas that may not be supported by local communities.

It might be argued that seeking to place MPAs in areas with relatively low fishing pressure amounts to little more than ‘residual conservation’: protecting the areas that least need protection (Pressey, 2009). However, it should be noted that a key constraint of the reserve selection process using Marxan is that MPA net-
works must achieve the specified conservation target. Thus, sites with high fishing pressure are not avoided at all cost. If a conservation feature is spatially associated with areas of high fishing pressure it will still be represented in the MPA network, even though important fishing grounds may be lost. Attempting to minimise opportunity costs ensures that where there is a choice of sites to achieve the conservation objective, the one that will cause the least conflict with fishers is selected.

None of the surrogates that we tested provided an accurate representation of resource use at fine spatial scales. Nevertheless, our results indicate that models based on the number of fishers or boats can assist in identifying regional-scale conservation priorities. These could be used to identify areas with relatively low fishing pressure, where conservation objectives may be met more easily (Green et al., 2009).

Philippine legislation states that local government units should maintain a registry of municipal fisherfolk and fishing vessels three gross tons and below (Executive Order 305). However, we found that these data were not available at barangay level for Siquijor, prompting our surveys. The national legislation does not make it clear which local authority should be responsible for keeping these records; the Municipal Agricultural Offices on Siquijor undertook fishing vessel registration prior to 2000, but these records have not been updated in recent years (A. Bucol, personal communication). Additionally, interviewees indicated that registration fees present a disincentive for fishers to register their boats. Our results indicate that, in the absence of empirical data on fishing effort, this information can be used to design conservation plans that reduce opportunity costs to small-scale fishers, which we believe will result in greater community acceptance and likelihood of successful implementation. We therefore recommend that attempts be made to establish and strengthen legislation requiring the collection of fisher and boat registrations, and to provide better incentives for fishers to obtain the relevant licenses.

The effectiveness of socioeconomic surrogates is likely to be sensitive to the spatial scale at which analysis is undertaken. At large spatial scales population may be a good indicator of fishing pressure: data for the number of fishers in each province of the Central Visayas region of the Philippines (Green et al., 2004) indicates a very strong positive relationship between population size and fishing effort at this scale. However, at the local (barangay) scale, we found that surrogates based on population data predicted the spatial distribution of fishing effort poorly. In rural areas with lower population density, a high proportion of households are dependent upon fishing as their primary source of income, as there are few opportunities for alternative employment. Interviewees in more urbanised barangays indicated that fewer people were engaged in fishing because other livelihoods, such as construction or small-scale enterprise, were more profitable. Some also suggested that lower water quality in areas adjacent to population centres, resulting from the use of detergents and chlorine-based products to wash clothes, were a disincentive to fishing. The fine spatial scale at which coastal resource management is undertaken in the Coral Triangle region requires that conservation planners consider which surrogates are likely to best represent the opportunity costs of conservation at this scale.

As per previous studies (Carwardine et al., 2008; Ban et al., 2009), we found that conservation priorities emerged as increasingly complex socioeconomic data were incorporated in MPA network design. Our conservation objective to represent 10% of reef-associated habitats in MPAs is relatively modest (yet realistic). Sensitivity analyses (not shown here) demonstrated that with higher representation targets, conservation priorities, and differences between the surrogate scenarios, became more pronounced. In regions where the opportunity cost of sites is more variable than their biodiversity value (either real, or perceived due to data limitations), costs should be used to drive the selection of sites for conservation (Naidoo et al., 2006). Grantham et al. (2008) found strongly diminishing return on investment for biodiversity survey data: increasing data collection effort did not result in significantly more effective protected area networks. Our experience suggests that the quality of socioeconomic data may be improved more quickly and economically than biodiversity data, and may have a more significant impact on the end-result of conservation plans.

Planning units containing existing MPAs were less costly than other sites under the empirical data scenario, indicating that our assumption that patterns of fishing effort reflect the cost of MPA implementation to coastal communities is valid: MPAs have been established in areas with relatively low fishing pressure. However, existing MPAs were not selected for inclusion in MPA networks more than would be expected by chance, indicating that they are not placed in areas of high conservation importance. This is likely a result of the approach to MPA implementation taken in the region, which has been characterised by opportunistic, site-level initiatives, rather than regional-scale systematic site-selection exercises, as we have performed here (Lowry et al., 2009). Nevertheless, although the existing MPAs on Siquijor may not be optimally sited for regional-scale conservation, they may provide local-scale benefits for fisheries management, conservation and socioeconomic development (e.g. income from tourism).

Despite a lack of formal marine tenure (as seen in the Solomon Islands and Papua New Guinea, amongst others (Foale and Manele, 2004)), we found that fishers utilizing coral reef or seagrass habitats typically identified fishing grounds only in areas adjacent to their barangay. Fishers using hook and line in open water travelled beyond their barangay, but rarely identified fishing grounds outside of their municipality. This has implications for the way that opportunity costs of conservation should be incorporated into conservation planning. Here, we sought to minimise the opportunity costs to small-scale fishers as a single stakeholder group. However, in this context it may be more important to minimise costs to individual communities separately (Ban and Klein, 2009). The effect of local marine tenure on regional-scale conservation planning has not yet been investigated, and should be a priority for future research.

Acknowledgements

The authors would like to thank the fishers of Siquijor for their cooperation, without which this research would not have been possible. We thank Natalie Ban and two anonymous reviewers for helpful comments on a previous version of the manuscript.

RW is supported by a Northcote Graduate Scholarship.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.biocon.2010.02.031.

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